Investigating dietary patterns and organisational structure by using stable isotope analysis: a pilot study of the Danish medieval leprosy hospital at Næstved

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With 3 figures and 5 tables

Summary: During the 12th and 13th centuries, numerous leprosy hospitals were founded in Europe. Given that leprosy was not considered infectious, this may reflect social dimensions of the disease. Aiming at exploring the impact of leprosy on medieval people and the organisation of the Danish *leprosarium* at Næstved, we reconstructed the diet of twenty patients using stable isotopes, and compared our results with relevant historical data. The isotope results revealed a terrestrial C_3 diet with a small contribution of aquatic foods. Contrary to historical evidence of daily fish consumption in the leprosy hospital, only six individuals consumed relatively large amounts of freshwater fish. *Leprosaria* have been considered monastic institutions, and thus a varied diet, poor in aquatic protein, questions the monastic nature of the hospital and points to a social stratification. A multi-isotope analysis of a larger sample set would add to our understanding of the diet of the leprosy patients, as well as their treatment in the *leprosarium*.

Key words: leprosy, diet, carbon isotopes, nitrogen isotopes, medieval Denmark

Leprosy is a severely debilitating and crippling disease, which changes the physical appearance of its sufferers and stigmatises them physically, psychologically and socially. The disease affects the skin and the peripheral nerves, leading to paralysis of muscle groups in the extremities and subsequent deformity of bones (Job et al. 1966; Lockwood et al. 2012); as well as secondary infection that is facilitated by loss of sensitivity to pain, ulceration of the skin and invasion by environmental pathogens (Roberts and Manchester 2005). Initial skin changes may be quite visible, as is also the involvement of the eyelids, which leads to loss of eye function and blindness (Daniel et al. 1997; Lynnerup and Boldsen 2012). Sufferers may thus exhibit pronounced, visible signs that may lead to stigmatisation with immense social and psychological implications (Heijnders 2004; Rafferty 2005; Lusli et al. 2015). The social stigmatisation of medieval leprosy sufferers has been widely debated by modern scholars (cf. Brody 1974; Touati 2000; Rawcliffe 2006; Boldsen 2009).

Influenced by socioeconomic, cultural and moral determinants, the social dimensions of the disease are closely related to, and thus reflect, the cultural traditions of each society (Bainson and van den Borne 1998). The establishment, therefore, of leprosy hospitals was a reaction to the disease during the High Medieval period when the notion of contagion was not yet established (Rawcliffe 2006). Because leprosy was considered more as a disease of the soul (Roberts and Manchester 2005), this gives an insight into the medieval mentality towards diseases and social relations. The investigation of the link between leprosy and leprosy hospitals (*leprosaria*) is thus essential for improving our knowledge on how the disease affected institutionalised individuals and society as a whole. This paper aims to explore this link through an isotopic investigation of the dietary patterns and behaviours of medieval leprosy sufferers, complemented further by information from historical sources.

The reconstruction of past human diets is important for understanding how communities were organised, revealing for example distinctions between different sex, age and social groups, as well as the level of health (e.g. Kjellström 2005; Yoder 2012; Beaumont and Montgomery 2016). Our knowledge of diets in medieval *leprosaria* derives mainly from regulation documents of the institutions. The amount and types of foods consumed by the patients of the *leprosaria* depended on the availability of goods and the economic status of each institution. Richards (1977) and Rawcliffe (2006) present several examples for Scandinavian and English *leprosaria* respectively. However, evidence of corrupt administration at *leprosaria* raises doubts about the implementation of the regulations mentioned in the historical texts. For example, according to a document dated to 1492, every morning the patients of the Danish *leprosarium* at Næstved were provided with porridge, fish and beer, but on meat days with either pork, beef or just cabbage, depending on availability (Richards 1977). The same document, however, reveals that the leprosy patients lodged a complaint to the king concerning their warden, who withheld their income, a condition that could have further influenced their diet. A similar event occurred at the *leprosarium* at Hedon in England, when, in 1334, the administrative body proceeded in the reduction of the daily dietary allowances (Rawcliffe 2006). Examples of corruption are also known from other medieval *leprosaria*, such as those at Kronoby, Finland and Svendborg, Denmark (Richards 1977).

Unlike historical sources, however, which may provide debatable information about past diets, the method of carbon and nitrogen stable isotope analysis not only provides a means for determining what people were actually eating, but may also provide information to reconstruct the issue of stigma attached to the disease. For example, Taylor et al. (2013) isotopically analysed rib and femur samples from three skeletons excavated from the cemetery of the medieval *leprosarium* of St. Mary Magdalen in Winchester (England), and revealed that the carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope ratios were enriched in the rib compared to the femur samples in all three individuals. Since bone material undergoes replacement at a faster rate in ribs than it does in femora, Taylor et al. (2013) interpreted this as indicating an increased consumption of marine foods during the last years of life, when these individuals were probably living in the *leprosarium*. Taylor et al. (2013) further suggested that this implied a monastic diet was imposed on the leprosy patients. The present study will conduct an isotopic dietary reconstruction of twenty leprosy patients from the Danish medieval *leprosarium* at Næstved, that will be compared with dietary information from historical sources. This study hopes to further explore the organisational structure of this *leprosarium*.

Materials and methods

The samples analysed in this study are from the medieval *leprosarium* at Aaderup, a suburb of the town of Næstved in Denmark (**Figure 1**). The *leprosarium* was first commemorated in a will that is dated to 1261 (Madsen 1990:8) and functioned for almost 300 years until 1542, when it was allocated to the House of the Holy Ghost (Helligåndshuset) in Næstved (Michelsen 1954).

Twenty skeletons (ten male and ten female) were selected, all aged between 20 and 45 years at death. The determination of sex was based on the morphological features of the pelvis and the skull (Phenice 1969; Ferembach et al. 1980; Buikstra and Ubelaker 1994; Loth and Henneberg 1996) as well as metrical methods (Bass 2005), while age was estimated, when applicable, by the morphological changes of the auricular surface (Lovejoy et al. 1985), the pubic symphysis (Brooks and Suchey 1990), the sternal rib end (Işcan et al. 1984) and the closure of ectocranial sutures (Meindl and Lovejoy 1985).

Rib fragments were sampled, since collagen in ribs remodels faster than in any other skeletal element, allowing us to gain dietary information for the last 3 to 5 years of life (Jørkov et al. 2009). We do not know how long the sampled individuals had been in the Næstved *leprosarium*, but sampling ribs maximises the chance of obtaining dietary information for the time of internment. Ribs with pathological lesions were avoided, because the effect of pathological changes on isotope ratios is not sufficiently understood (Katzenberg and Lovell 1999). The samples were taken from the mid-shaft using a low-speed drill, and the first, second, eleventh and twelfth ribs were not included (Jørkov et al. 2009).

All samples weighed up to 200 mg and grinding was avoided, as this would damage proteins and other bone biopolymers (Collins and Galley 1998).

[>>> Figure 1 <<<]

Collagen extraction was based on a modification of the Longin (1971) method by Brown et al. (1988) that includes an additional ultrafiltration step. The isotopic measurements were run in duplicate at the Stable Isotope Biogeochemistry Laboratory (SIBL) at Durham University. Total carbon and nitrogen content, and stable isotope analysis were performed using a Costech Elemental Analyser (ECS 4010) connected to a Thermo Scientific Delta V Advantage isotope ratio mass spectrometer. Isotopic accuracy was monitored through routine analyses of in-house standards and international standards (e.g., USGS40, USGS24, IAEA-600, IAEA-N-1, IAEA-N-2): Analytical uncertainty in carbon and nitrogen isotope analysis was typically <±0.1 ‰ for replicate analyses of the international standards and <0.2 ‰ on replicate sample analysis. Total organic carbon and nitrogen data was obtained as part of the isotopic analysis using an internal standard (Glutamic Acid, 40.82 % C, 9.52 % N).

The non-parametric Kolmogorov-Smirnov two-sample test was performed in order to explore potential dietary differences between the two sexes (Siegel and Castellan 1988). Instead of a parametric, a non-parametric, test was preferred because the size of the samples tested is small (under twenty) (Madrigal 2012).

Results

Table 1 presents in detail the quality indicators and the isotopic values obtained from each sample. Except for a single outlier (371), all samples fall within the suggested range of atomic C/N ratio (2.9–3.6) for well-preserved collagen (DeNiro 1985; Ambrose 1990). Thus, the isotopic values of sample 371 were not considered. The collagen yield and carbon and nitrogen percentages of all samples fall within the range proposed by van Klinken (1999). The $\delta^{13}C$ values range from -20.8‰ to -19.2‰ (mean = -20‰), while the $\delta^{15}N$ values range from 9.9‰ to 12.9‰ (mean = 11.7‰). Males have $\delta^{13}C$ values ranging from -20.3‰ to -19.2‰ (mean = -19.8‰) and $\delta^{15}N$ values ranging from 11.3‰ to 12.6‰ (mean = 11.9‰). Females have $\delta^{13}C$ values ranging from -20.8‰ to -19.6‰ (mean = -20.2‰) and $\delta^{15}N$ values ranging from 9.9‰ to 12.9‰ (mean = 11.6‰).

The narrow range of the $\delta^{13}C$ values suggest that the individuals from Næstved had a diet dominated by terrestrial C_3 based foods (Johansen et al. 1986). The majority of the analysed individuals had $\delta^{13}C$ values around -20‰, corresponding to a diet with little or no marine protein (Richards and Hedges 1999; Olsen et al. 2018). The $\delta^{15}N$ values exhibit a range from 9.9‰ to 12.9‰, suggesting that animal protein may have contributed significantly to the diet, since a diet consisting of protein from both plants and animals would give lower $\delta^{15}N$, around 6–9‰ (Jørkov et al. 2010). The consumption of omnivores, for example, pigs feeding on slops (Müldner and Richards 2005) has been connected with the combination of an entirely terrestrial $\delta^{13}C$ signal with high $\delta^{15}N$ values. However, Halley and Rosvold (2014) indicate through $\delta^{13}C$ and $\delta^{15}N$ that domestic pigs from medieval sites of northern Europe had a wide range of diets in different areas. Furthermore, the study of a single pig from the Danish medieval site of Øm Kloster gave a $\delta^{15}N$ of 6‰ corresponding to an herbivorous diet (Yoder, 2010). The consumption of manured plants, as well as freshwater and suckling animals may also explain the combination of high $\delta^{15}N$ with terrestrial $\delta^{13}C$ (Müldner and Richards 2005; Jay and Richards 2006; Jørkov et al. 2010).

The Kolmogorov-Smirnov tests revealed no significant difference between the diets of men and women ($Z = 1.06$, $p = 0.21$ for $\delta^{13}C$ and $Z = 0.75$, $p = 0.63$ for $\delta^{15}N$).

[>>> Table 1 <<<]

Discussion

During the medieval period, cereals constituted the main food consumed, with barley and winter rye being the main crops, while wheat was considered as a luxury food source (Stone 2006a). According to Yoder (2012), sheep, pigs and cattle provided the highest proportions of protein intake, while before the later 14th century and the intensification of cattle production in Denmark, dairy products and eggs were also an important source of protein. Rawcliffe (2006) further mentions that eggs and fresh milk, among other products, were considered beneficial for leprosy. In antithesis to fresh fruit and vegetables that were considered inappropriate food for the upper class (Dyer 1983), the consumption of birds was a privilege of the aristocracy and the clergy; a concept that rose to prominence during the late 14th century (Stone 2006b).

The $\delta^{13}C$ and $\delta^{15}N$ values in this study reveal a diet based on C_3 plants and various amounts of terrestrial and aquatic protein for both male and female leprosy patients. For a better interpretation of the human isotope data, it is important to have data from a variety of faunal samples from the same period and location. It was not possible, however, to obtain animal bones from the area of the *leprosarium*. **Figure 2** depicts the $\delta^{13}C$ and $\delta^{15}N$ values of the leprosy patients, as well as the values of terrestrial and aquatic animals mentioned by Yoder (2010, Table 1). This data comes from the Danish medieval monastery at Øm Kloster (Yoder 2010), the English medieval sites of St. Giles and Beverley (a Dominican priory) (Müldner and Richards 2005), as well as from Neolithic sites in Denmark (Fischer et al. 2007) and medieval sites in northern Europe (Barrett et al. 2008).

All the marine fish (ling, haddock, cod and herring) have more positive $\delta^{13}C$ and $\delta^{15}N$ than the humans, while the herbivores (goat, cow, sheep and pig) have more depleted values. There is a progressive enrichment of $\delta^{13}C$ (1‰ to 2‰; Bocherens and Drucker 2003; Brown & Brown 2011:84) and $\delta^{15}N$ (3‰ to 5‰; Schoeninger et al. 1983; Bocherens and Drucker 2003) from the lower to higher trophic levels in the food chain. The enrichment of ^{15}N enables the differentiation between animal and plant resources (Schoeninger et al. 1983), while carbon stable isotopes distinguish between plants that follow different photosynthetic pathways (C_3 *versus* C_4), as well as between terrestrial and marine resources (Tauber 1981; DeNiro 1985). The lower $\delta^{15}N$ of the herbivores indicates that they could have been a staple food source for the leprosy patients. Only one pike sample (pike 2) could possibly contribute to the diet (pike is a freshwater fish). $\delta^{13}C$ values that indicate a terrestrial C_3 diet and are combined with $\delta^{15}N$ values over 12‰, reflect a significant contribution of freshwater fish (Jørkov et al. 2010, based on Bonsall et al. 1997). The daily consumption of fish by the patients of the *leprosarium* at Næstved is recorded in a 15th century document (Richards 1977). However, from a total of nineteen samples, only six have nitrogen values greater than 12‰. Relative dating, in the form of the arrangement in the grave of the arms in relation to the rest of the body, is available for four of these samples (**Figure 3**).

[>>> Figure 2 <<<]

The arm-position method is used widely in Denmark for medieval contexts until the Reformation in 1536 (after this period older positions came into use again), as it provides a broad, but rather consistent method for dating. The four arm positions (Position A, AD 1000–1300, arms next to the body; Position B, AD 1300–1350, forearms over the lower parts of the abdomen and hands over the pelvic region; Position C, AD 1350–1400, forearms over the upper part of the abdomen, with elbows flexed at approximately 90˚; Position D, 1400–1536, forearms crossed over the chest and hands on the shoulders) have been described by Kieffer-Olsen (1993), and the dates are assigned by Jantzen et al. (1994) based on the dominant arm position for each period. No chronological pattern can be observed in the diet of the sampled individuals.

[>>> Figure 3 <<<]

In medieval England, as fishing rights in local streams and rivers were a privilege of the aristocracy, freshwater fish were regarded to be an expensive foodstuff (Dyer 1988; Hoffman 1996). Rawcliffe (2006), however, mentions the individuals with leprosy from Boughton, England, who owned the right of keeping a boat and fishing in the river Dee. Suså, the longest river in southern Zealand, flows through Næstved and was probably the source of the freshwater fish for the population of the surrounding area. The high cost of freshwater fish is emphasised by the frequency of ponds found in relation to land owned by aristocrats (Dyer 1994; Serjeantson and Woolgar 2006). Eel, bream, perch, pike, roach and tench were the most common fish consumed by the upper class, and they could be found in both ponds, rivers and streams (Dyer 1988). Hybel and Poulsen (2007) mention that fishponds are frequently encountered in Danish sources that date after the late 14th century. The *leprosarium* at Næstved owned an area of forest and at least one farm (Richards 1960), although the existence of a pond remains unknown.

Compared to freshwater fish, marine fish were possibly more affordable due to their greater availability, which lowered their market value (Hoffmann 1996). In northern Europe there was a wide trade of herring and cod during the Medieval period (Enghoff 1996; Barrett et al. 2008; 2011). The establishment of major marine fisheries, combined with the fasting rules that prohibited the consumption of meat, eggs and dairy products for a large number of days of the year (Dyer 1988; Müldner and Richards 2005) would suggest that marine fish were an important component of the Danish medieval diet. A zooarchaeological study focusing on herring bones that date between the 8th and 13th centuries uncovered large scale activity on Zealand (Enghoff 1996). Moreover, bones from marine fish, such as ling, cod, dab and salmon, as well as from freshwater fish, such as pike, perch, bream and sturgeon, have also been discovered at medieval sites (Arcini 1999).

Yoder (2012) claims that due to the high cost of meat, the lower class probably ate fish more frequently than the upper class. On the contrary, based on historical documents, Dyer (1983) suggests that the upper class was more likely to follow the fasting rules, and therefore consumed larger quantities of fish. Even though the drying and salting of marine fish for preservation was common, Hoffmann (1996) suggests that difficulties of transporting fresh marine fish to the mainland for immediate consumption probably made freshwater fish more desirable even after the expansion of the marine fish trade. Although Næstved´s close proximity to the sea suggests access to marine resources, there is no evidence of significant consumption of marine food in the population from the nearby *leprosarium*. This has also been noted for other coastal sites, such as the late Anglo-Saxon site in Bishopstone, England, where stable isotope analysis revealed a terrestrial-based diet with only a small input of marine protein (Marsall et al. 2010) – here, too, in contrast to the large amount of recovered marine fish bones (Reynolds 2010). A diet that is completely dependant on marine resources is expected to have δ^{13}C values of approximately -12‰, while a diet that is based on purely C_3 plants and terrestrial animals is expected to have values of around -20‰ (Richards and Hedges 1999). Several studies have produced carbon and nitrogen stable isotope values that indicate either a mixed diet or purely terrestrial/marine diets (e.g. Schulting et al. 2008; Keenleyside et al. 2009; Schwarcz et al. 2014; Müldner 2016). **Table 2** provides the mean carbon and nitrogen values of various populations from northern Europe. Noteworthy is the progressive enrichment of δ^{13}C values from purely terrestrial to mixed and marine diets, as well as the fact that, in some cases, coastal populations had a minimal dietary contribution of marine protein (e.g. a late Anglo-Saxon population from England; Marsall et al. 2010 and a medieval population from Sweden; Linderholm and Kjellström 2011).

[>>> Table 2 <<<]

The limited contribution of marine resources in the diet of the leprosy patients, in combination with the fact that only six of them have δ^{15}N values indicative of some contribution of freshwater fish to the diet (greater than 12‰; Jørkov et al. 2010, based on Bonsall et al. 1997), suggests that the information provided by the 15th century historical source (i.e, daily consumption of fish by the leprosy patients) from Næstved (Richards 1977) is incorrect. Furthermore, this may indicate that less than half of the individuals included in our study followed the fasting rules. Taking into account that the total number of fasting days covered approximately half of a year's duration (Yoder 2012), it remains uncertain to what extent leprosy patients from Næstved followed the religious food restrictions.

Isotopic analysis for the dietary reconstruction of individuals with bone lesions of leprosy has also been conducted in three other sites: the medieval *leprosarium* of St. Mary Magdalen in Winchester, England (Roffey et al. 2017); a medieval cemetery in Norwich, England (Bayliss et al. 2004); and a medieval cemetery in Sigtuna, Sweden (Linderholm and Kjellström 2011) (**Table 3**). $\delta^{13}C$ and $\delta^{15}N$ values indicate a diet based on C_3 plants and various amounts of terrestrial and aquatic protein for all four sites. It is noteworthy however, that all samples from the *leprosarium* at Winchester and the cemetery in Norwich (probably also related to a *leprosarium*) have slightly higher $\delta^{15}N$ and more positive $\delta^{13}C$ than the samples from Næstved, indicating a higher consumption of marine protein. All four samples from Sigtuna have similar $\delta^{13}C$ values to Næstved, but higher $\delta^{15}N$, indicating more consumption of freshwater fish; however, these skeletons come from a regular, parish cemetery and are not linked to a *leprosarium*.

A similar diet to that recorded for the leprosy patients from Næstved is also evident for another four, Danish cemeteries, contemporary to the *leprosarium* (**Table 4**). These are located at the town of Holbæk (Jørkov et al. 2009), which is approximately 63 km north of Næstved, at the rural Cistercian monastery at Øm Kloster, at the important administrative, ecclesiastical and mercantile city of Viborg and at Ribe, one of the largest cities in medieval Denmark (Yoder 2010).

[>>> Table 3 <<<]

[>>> Table 4 <<<]

Small variations between the mean $\delta^{13}C$ and $\delta^{15}N$ values of these sites suggest that the diet of the individuals from Holbæk and Øm Kloster consisted of C_3 plants and animals, such as pigs, sheep and cows, as well as a relatively small amount of freshwater fish, whereas the diet of the individuals from the larger urban site, Ribe, included large amounts of fish, both marine and freshwater (Yoder 2010). The diet of the individuals from Viborg, seems to be intermediate between the diets from the other sites. The mean values of the individuals from the *leprosarium* appear to be closer to the mean $\delta^{13}C$ and $\delta^{15}N$ values of the individuals from Øm Kloster. However, when taking into consideration the different social groups from the monastery, the mean values of the leprosy patients are closer to the values of the peasants (**Table 5**). Yoder (2006) explores the status-based differences in the diet of the peasants, the monks and the elites from Øm Kloster, with the social class being distinguished by the location of the burial in relation to the church. The diet of the leprosy patients seems to be more closely related to that of the peasant group, which consisted of C_3 plant and terrestrial animal proteins with only a small contribution of aquatic foods.

[>>> Table 5 <<<]

Dietary variation in the *leprosarium* and possible interpretations

It has been proposed that medieval leprosy hospitals were monastic institutions, and that the leprosy patients had to follow a monastic life of daily prayers and a uniform diet defined by the fasting rules (Rawcliffe 2001; 2006). The $\delta^{13}C$ and $\delta^{15}N$ values of the leprosy patients from Næstved, however, do show some variation, suggesting a homogeneous diet was not prevalent. Since people from the entire social spectrum were admitted at Danish *leprosaria* (Dahl 2001), and due to bone turnover rates, this could partially reflect social status variation of the pre-*leprosarium* period. Nevertheless, it may also indicate a social inequality among the patients of the *leprosarium*, which could further be related to the organisational structure of the institution.

In contrast to British *leprosaria* that depended heavily on endowments, gifts and alms provided by wealthy individuals (Richards 1977; Roberts 1986), *leprosaria* in Scandinavia mainly acquired their income through taxes paid by local communities (Richards 1960). The dependence of the Danish *leprosaria* on the taxes paid by the local communities, from which they further had the obligation to receive infected individuals (Ehlers 1898), reveals a direct correlation between *leprosaria* and the economic state of the communities that supported them. The economic situation of each community, therefore, which might have varied over time, must have had a considerable impact on the organisation of the leprosy institutions, and thus on the diet of the patients. As we do not have precise information on the dating of our samples, the variation we see could simply reflect the changing ability of the local community to support the *leprosarium*.

Unlike the main economic source (a tax-collection system) for the *leprosaria* in Denmark, that could have been independent of religious guidelines for equality and sharing, the religious motives of the benefactors of British *leprosaria* may have constituted the stimulus for the hospitals to turn to a monastic lifestyle, aiming at attracting more donations. Rawcliffe (2001:250) mentions that punishment with the imposition of strict fasting and public repentance was not only frequent, but also a means by which a leprosy patient would become “a more potent intercessor for benefactors and patrons”. However, Rawcliffe (2001:233) also refers to high status patients in British *leprosaria*, “whose rank merited more solicitous treatment”. Nevertheless, the benefits of a higher social status within the leprosy community could have been restricted to differences in the type of accommodation and burial location (cf. Roffey and Tucker 2012), without further encompassing a more varied diet.

Conclusions

The isotopic study of the *leprosarium* at Næstved has generated a better reconstruction of dietary patterns and behaviours . The $\delta^{13}C$ and $\delta^{15}N$ values reveal a diet based dominantly on C_3 plants, meat (very likely also eggs and dairy products) and fish for both men and women. However, the contribution of marine proteins to the diet of most of the leprosy patients was limited, and only six individuals had a diet that was significantly enriched by freshwater fish (combination of low $\delta^{13}C$ values with $\delta^{15}N$ higher than 12‰). This contradicts the 15th century historical source that refers to a daily consumption of fish by the patients of the Næstved leprosy hospital (Richards 1977), something that emphasises the importance of approaching the study of past diets through a combination of different methods. Furthermore, a diet poor in aquatic protein raises questions regarding the adherence to the fasting rules, and consequently to the monastic nature of the hospital. Finally, the diet of the patients was similar to that consumed by the non-leprous individuals from surrounding areas to the institution, especially to the diet of the peasant group from Øm Kloster, as well as to the diet of leprous individuals from other leprous and non-leprous contexts.

This study highlights the importance and value of stable isotope analysis in understanding diet in ancient hospitals and *leprosaria*. It is however, a pilot study and the number of analysed skeletons is rather small. An expansion of the research, with the inclusion of individuals from additional Danish medieval *leprosaria*, would provide a more complete picture of medieval diets in the region, including our knowledge and understanding of the organisational structure of such institutions.

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References

Ambrose, S.H. (1990): Preparation and characterisation of bone and tooth collagen for isotopic analysis. – J. Archaeol. Sci. **17**: 431–451.

Arcini, C. (1999): Health and disease in early Lund, Osteo-pathologic studies of 3,305 individuals buried in the cemetery area of Lund 990-1536. – Lund University Publications**,** Lund.

Bainson, K.A. & Borne, B. van den (1998): Dimensions and process of stigmatization in leprosy. – Lepr. Rev. **69**: 341–350.

Barrett, J. et al. (2008): Detecting the medieval cod trade: a new method and first results. – J. Archaeol. Sci. **35**: 850–861.

Barrett, J. et al. (2011): Interpreting the expansion of sea fishing in medieval Europe using stable isotope analysis of archaeological cod bones. – J. Archaeol. Sci. **38**: 1516–1524.

Bass, W.M. (2005): Human Osteology: A Laboratory and Field Manual (fifth edition). – Special Publication No. 2 of the Missouri Archaeological Society, Springfield.

Bayliss, A. et al. (2004): The potential significance of dietary offsets for the interpretation of radiocarbon dates: an archaeologically significant example from medieval Norwich. – J. Archaeol. Sci. **31**: 563–575.

Beaumont, J. & Montgomery, J. (2016): The Great Irish Famine: Identifying Starvation in the Tissues of Victims Using Stable Isotope Analysis of Bone and Incremental Dentine Collagen. – PLoS ONE **11**: e0160065.

Bocherens, H. & Drucker, D. (2003): Trophic level isotopic enrichment of carbon and nitrogen in bone collagen: case studies from recent and ancient terrestrial ecosystems. – Int. J. Osteoarchaeol. **13**: 46–53. Boldsen, J.L. (2009): Leprosy in Medieval Denmark: Osteological and epidemiological analyses. – Anthrop. Anz. **67**: 407–425.

Bonsall, C. et al. (1997): Mesolithic and early Neolithic in the Iron Gates: a palaeodietary perspective. – J. Europ. Archaeol. **5**: 50–92.

Brody, S.N. (1974): The Disease of the Soul: Leprosy in Medieval Literature. – Cornell University Press, Ithaca, New York and London.

Brooks, S. & Suchey, J.M. (1990): Skeletal age determination based on the os pubis: A comparison of the Acsádi-Nemeskéri and Suchey-Brooks methods. – Hum. Evol. **5**: 227–238.

Brown, T.A. et al. (1988): Improved collagen extraction by modified Longin method. – Radiocarbon **30**: 171–177.

Brown, T. & Brown, K. (2011): Biomolecular Archaeology. An introduction. – Wiley-Blackwell, Oxford.Buikstra, J.E. & Ubelaker, D.H. (eds.) (1994): Standards for Data Collection from Human Skeletal Remains: Proceedings of a Seminar at the Field Museum of Natural History organized by Jonathan Haas. – Arkansas Archeological Survey (Research Series **44)**, Fayetteville.

Collins, M.J. & Galley, P. (1998): Towards an optimal method of archaeological collagen extraction: The influence of pH and grinding. – Ancient Biomolecules **2**: 209–222.

Dahl, S. C. (2001): Næstved i Middelalderen. Købstadens oprindelse, dens udseende og indbyggernes tro, levevilkår og dagligdag. – Suså-Komiteen, Næstved.

Daniel, E. et al. (1997): Pathology of iris in leprosy. – Br. J. Ophthalmol. **81**: 490–492.

DeNiro, M.J. (1985): Postmortem preservation and alteration of *in vivo* bone collagen isotope ratios in relation to palaeodietary reconstruction. – Nature **317**: 806–809.

Dyer, C. (1983): English Diet in the Later Middle Ages. – In: Aston, T.H. et al. (eds.): Social Relations and Ideas: Essays in Honour of R. H. Hilton. – Cambridge University Press, Cambridge, pp. 191–216.

Dyer, C. (1988): The consumption of fresh-water fish in medieval England. – In: Aston, M. (ed.): Medieval fish, fisheries and fishponds in England. – BAR British Series **182**: 27–38.

Dyer, C. (1994): Everyday Life in Medieval England. – Hambledon Press, London.

Ehlers, E. (1898): Danske St. Jørgensgaarde i Middelalderen. Særtryk af Bibliotek for Læger. Udarbejdet med understøttelse af det Classenske Fideicommis. – Fr. Baggesbogtrykkeri, Kjøbenhavn.

Enghoff, I.B. (1996): A medieval herring industry in Denmark and the importance of herring in eastern Denmark. – Archaeofauna **5**: 43–47.
Ferembach, D. et al. (1980): Recommendation for Age and Sex Diagnoses of Skeletons. – J. Hum. Evol. **9**: 517–549.
Halley, D.J. & Rosvold, J. (2014): Stable isotope analysis and variation in medieval domestic pig husbandry practices in northwest Europe: absence of evidence for a purely herbivorous diet. – J. Archaeol. Sci. **49**: 1–5.
Heijnders, M.L. (2004): The Dynamics of Stigma in Leprosy. – Int. J. Lepr. Other Mycobact. Dis. **72**: 437–447.
Hoffmann, R.C. (1996): Economic Development and Aquatic Ecosystems in Medieval Europe. – Am. Hist. Rev. **101**: 631–669.
Hybel, N. & Poulsen, B. (2007): The Danish Resources c. 1000-1550: Growth and Recession. – Brill (The Northern World Series **34**), Leiden and Boston.
Işcan, M.Y. et al. (1984): Age estimation from the rib by phase analysis: white males. – J. Forensic Sci. **29**: 1094–1104.
Jantzen, C. et al. (1994): De små brødres hus i Ribe. – Mark og montre **30**: 26–36.
Jay, M. & Richards, M.P. (2006): Diet in the Iron Age cemetery population at Wetwang Slack, East Yorkshire, UK: carbon and nitrogen stable isotope evidence. – J. Archaeol. Sci. **33**: 653–662.
Job, C.K. et al. (1966): The histopathological appearance of leprous rhinitis and pathogenesis of septal perforation in leprosy. – J. Laryngol. Otol. **80**: 718–732.
Johansen, O.S. et al. (1986): δ^{13}C and Diet: Analysis of Norwegian Human Skeletons. – Radiocarbon **28**: 754–761.
Jørkov, M.L.S. et al. (2009): The petrous bone: a new sampling site for identifying early dietary patterns in stable isotopic studies. – Am. J. Phys. Anthropol. **138**: 199–209.
Jørkov, M.L.S. et al. (2010): Uniform diet in a diverse society. Revealing new dietary evidence of the Danish Roman Iron Age based on stable isotope analysis. – Am. J. Phys. Anthropol. **143**: 523–533.
Katzenberg, M.A. & Lovell, N.C. (1999): Stable isotope variation in pathological bone. – Int. J. Osteoarchaeol. **9**: 316–324.
Keenleyside, A. et al. (2009): Stable isotopic evidence for diet in a Roman and Late Roman population from Leptiminus, Tunisia. – J. Archaeol. Sci. **36**:51–63.Kieffer-Olsen, J. (1993): Grav og gravskik i det middelalderlige Danmark: 8 kirkegårdsudgravninger. – PhD thesis, submitted at Aarhus University, Aarhus.
Kjellström, A. (2005): The Urban Farmer: Osteoarchaeological Analysis of Skeletons from Medieval Sigtuna Interpreted in a Socioeconomic Perspective. – PhD thesis, submitted at Stockholm University, Stockholm.
Klinken, G.J. van (1999): Bone Collagen Quality Indicators for Palaeodietary and Radiocarbon Measurements. – J. Archaeol. Sci. **26**: 687–695.
Kosiba, S.B., Tykot, R.H. & Carlsson, D. (2007): Stable isotopes as indicators of change in the food procurement and food preference of Viking Age and Early Christian populations on Gotland (Sweden). – J. Anthrop. Archaeol. **26**:394–411.
Linderholm, A. & Kjellström, A. (2011): Stable isotope analysis of a medieval skeletal sample indicative of systemic disease from Sigtuna Sweden. – J. Archaeol. Sci. **38**: 925–933.
Lockwood, D.N. & Saunderson, P.R. (2012): Nerve damage in leprosy: a continuing challenge to scientists, clinicians and service providers. – Int. Health **4**: 77–85.
Longin, R. (1971): New Method of Collagen Extraction for Radiocarbon Dating. – Nature **230**: 241–242.
Loth, S.R. & Henneberg, M. (1996): Mandibular ramus flexure: a new morphologic indicator of sexual dimorphism in the human skeleton. – Am. J. Phys. Anthropol. **99**: 473–485.
Lovejoy, C.O. et al. (1985): Chronological metamorphosis of the auricular surface of the ilium: a new method for the determination of adult skeletal age at death. – Am. J. Phys. Anthropol. **68**: 15–28.
Lusli, M. et al. (2015): Dealing with Stigma: Experiences of Persons Affected by Disabilities and Leprosy. – BioMed Research International: 1–9.

Lynnerup, N. & Boldsen, J. (2012): Leprosy (Hansen's disease). In: Grauer, A.L. (ed.): A Companion to Paleopathology. – Wiley-Blackwell, Chichester, pp. 458–471.

Madrigal, L. (2012): Statistics for Anthropology. – Cambridge University Press, Cambridge.

Madsen, K. (1990): Spedalskhed og Sct. Jørgensgård (second edition). – Næstved Museum, Næstved.

Marsall, P. et al. (2010): Scientific dating evidence – In: Thomas, G. (ed.): The Later Anglo-Saxon Settlement at Bishopstone: a downland manor in the making. – Council for British Archaeology (Council for British Archaeology Report 163), York, pp. 157–164.

Meindl, R.S. & Lovejoy, C.O. (1985): Ectocranial suture closure: a revised method for the determination of skeletal age at death based on the lateral-anterior sutures. – Am. J. Phys. Anthropol. **68**: 57–66.Michelsen, F. (1954): St. Jørgensgården i Aaderup ved Næstved. – Historisk Samfund for Præstø (Årbog, Ny række **4**), Præstø, pp. 72–85.

Müldner, G. & Richards, M.P. (2005): Fast or feast: reconstructing diet in later medieval England by stable isotope analysis. – J. Archaeol. Sci. **32**: 39–48.

Müldner, G. (2016): Marine fish consumption in medieval Britain: the isotope perspective from human skeletal remains. – In: Barrett, J. and Orton, D. (eds.): Cod and herring: the archaeology and history of medieval sea fishing. – Oxbow Books, Oxford, pp. 239-249.Olsen, K.C., White, C.D., Longstaffe, F.J. & Rühli, F.J. (2018): Isotopic anthropology of rural German medieval diet: intra- and inter-population variability. – Archaeol. Anthropol. Sci. **10**:1053-1065.

Phenice, T.W. (1969): A newly developed visual method of sexing the os pubis. – Am. J. Phys. Anthropol. **30**: 297–302.

Rafferty, J. (2005): Curing the stigma of leprosy. – Lepr. Rev. **76**: 119–126.

Rawcliffe, C. (2001): Learning to Love the Leper: Aspects of Institutional Charity in Anglo Norman England. – In: Gillingham, J. (ed.): Proceedings of the Battle Conference 2000. – The Boydell Press (Anglo-Norman Studies XXIII), Woodbridge, pp. 231–250.

Rawcliffe, C. (2006): Leprosy in Medieval England. – The Boydell Press, Woodbridge.

Reynolds, R. (2010): Fish remains. – In: Thomas, G. (ed.): The Later Anglo-Saxon Settlement at Bishopstone: a downland manor in the making. – Council for British Archaeology (Council for British Archaeology Report 163), York, pp. 157–164.

Richards, M.P. & Hedges, R.E.M. (1999): Stable Isotope Evidence for Similarities in the Types of Marine Foods Used by Late Mesolithic Humans at Sites Along the Atlantic Coast of Europe. – J. Archaeol. Sci. **26**: 717–722.

Richards, P. (1960): Leprosy in Scandinavia. – Centaurus **7**: 101–131.

Richards, P. (1977): The Medieval Leper and his Northern Heirs. – Boydell and Brewer, Woodbridge.

Roberts, C. & Manchester, K. (2005): The Archaeology of Disease (third edition). – The History Press, Stroud.

Roberts, C. (1986): Leprosy and Leprosaria in Medieval Britain. – MASCA Journal **4**: 15–21.

Roffey, S. & Tucker, K. (2012): A contextual study of the medieval hospital and cemetery of St Mary Magdalen, Winchester, England. – Int. J. Palaeopathol. **2**: 170–180.

Roffey, S. et al. (2017): Investigation of a Medieval Pilgrim Burial Excavated from the *Leprosarium* of St Mary Magdalen Winchester, UK. – PLoS Negl. Trop. Diseases **11**: 1–27.

Schoeninger, M.J., DeNiro, M.J. & Tauber, H. (1983): Stable nitrogen ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. – Science **220**:1381–1383.

Schulting, R.J. et al. (2008): Stable carbon and nitrogen isotope analysis on human remains from the Early Mesolithic site of La Vergne (Charente-Maritime, France). – J. Archaeol. Sci. **35**:763–772.

Schwarcz, H.P., Chisholm, B.S. & Burchell, M. (2014): Isotopic Studies of the Diet of the People of the Coast of British Columbia. – Am. J. Phys. Anthropol. **155**:460–468.

Serjeantson, D. & Woolgar, C.M. (2006): Fish consumption in Medieval England. – In: Woolgar, C. et al. (eds.): Food in Medieval England: Diet and nutrition. – Oxford University Press (Medieval History and Archaeology Series), Oxford, pp. 102–130.

Siegel, S. & Castellan, N.J. (1988): Nonparametric statistics for the behavioral sciences (second edition). – McGraw-Hill, New York.

Stone, D.J. (2006a): The consumption of field crops in medieval England. – In: Woolgar, C. et al. (eds.): Food in Medieval England: Diet and nutrition. – Oxford University Press (Medieval History and Archaeology Series), Oxford, pp. 11–26.

Stone, D.J. (2006b): The Consumption and Supply of Birds in Late Medieval England. – In: Woolgar, C. et al. (eds.): Food in Medieval England: Diet and nutrition. – Oxford University Press (Medieval History and Archaeology Series), Oxford, pp. 148–161.

Tauber, H. (1981) ^{13}C evidence for dietary habits of prehistoric man in Denmark. – Nature **292**:332–333.

Taylor, G.M. et al. (2013): Detection and Strain Typing of Ancient *Mycobacterium leprae* from a Medieval Leprosy Hospital. – PLoS ONE **8**: e62406.

Touati, F.O. (2000): Contagion and leprosy. Myth, ideas and evolution in medieval minds and societies. – In: Conrad, L. & Wujastyk, D. (eds.): Contagion. Perspectives From Pre-Modern Societies. – Ashgate Publishing Limited, Tyne and Wear, pp. 163–177.

van der Sluis, L.G. et al (2016): A palaeodietary investigation of a multi-period churchyard in Stavanger, Norway, using stable isotope analysis (C, N, H, S) on bone collagen. – J. Archaeol. Sci. Reports **9**:120–133.

Yoder, C.J. (2006): The Late Medieval Agrarian Crisis and Black Death plague epidemic in medieval Denmark: a paleopathological and paleodietary perspective. – PhD dissertation, submitted at the Texas A&M University, Texas.

Yoder, C. (2010): Diet in medieval Denmark: a regional and temporal comparison. – J. Archaeol. Sci. **37**: 2224–2236.

Yoder, C. (2012): Let them eat cake? Status-based differences in diet in medieval Denmark. – J. Archaeol. Sci. **39**: 1183–1193.

Figures

Figure 1. Map of Denmark, showing the location of Næstved. The inset illustrates the distance between the medieval town of Næstved and its suburb, Aaderup. The location of the *leprosarium's* cemetery is marked by a cross. (Background map adapted from "Denmark physical map" by NordNordWest, based on a work by Urutseg *Public Domain Dedication license (CC0 1.0 Universal)*. Inset based on Madsen (1985:14, table IV)).

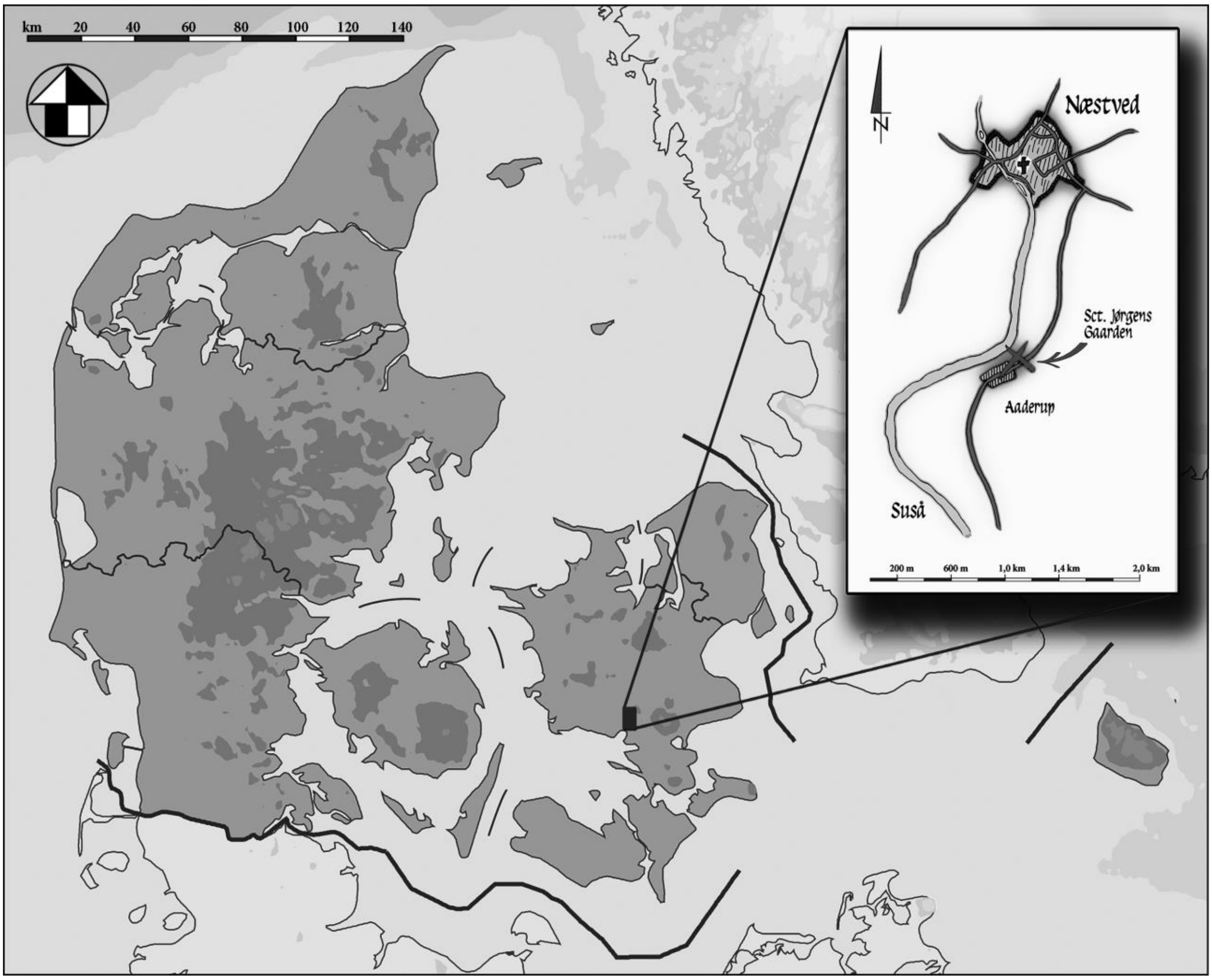


Figure 2. δ^{13}C and δ^{15}N values for the individuals from the *leprosarium* at Næstved (9 females, square; 10 males, circle) as well as for the animals mentioned by Yoder (2010, Table 1).

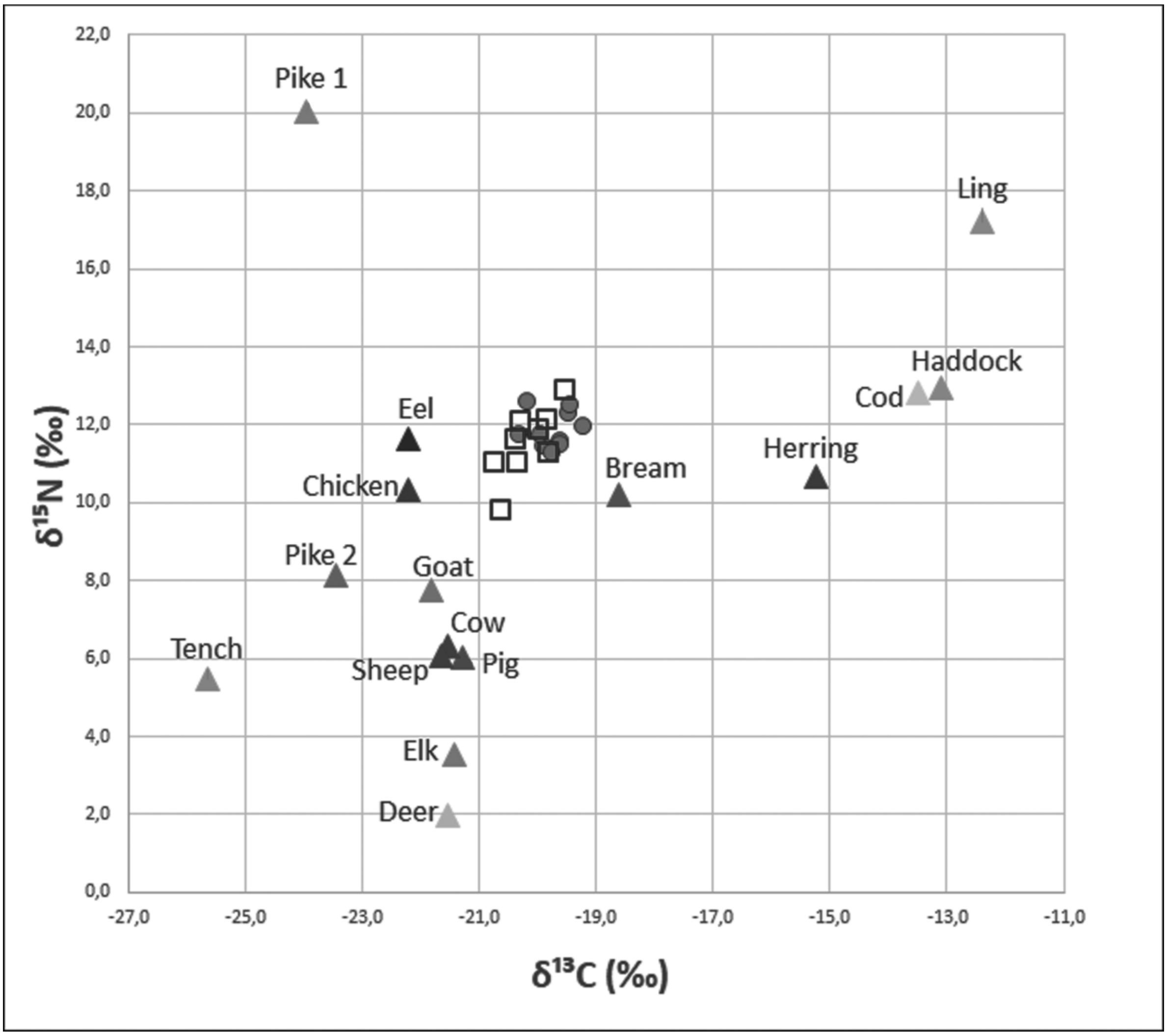
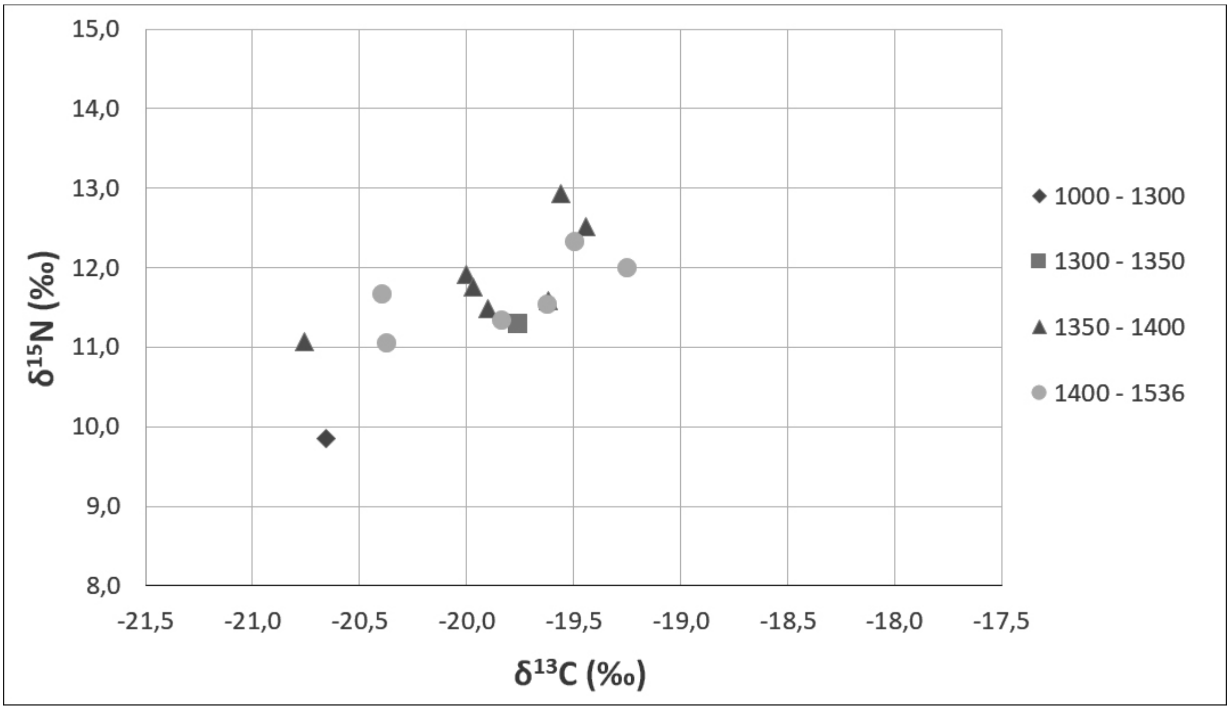


Figure 3 δ^{13}C and δ^{15}N of the leprosy patients from Næstved, grouped chronologically (information about the position of the arms was only available for fifteen skeletons).



Tables

Table 1 Collagen $\delta^{13}C$ and $\delta^{15}N$ values of the twenty skeletons from the leprosy hospital at Næstved.

Sample	Sex	Age	Elem.	C/N	C%	N%	$\delta^{13}C$	$\delta^{15}N$
41	male	35-45	rib	3.4	43.0	14.7	-20.2	12.6
78	male	25-40	rib	3.3	42.4	14.8	-20.3	11.7
99	female	25-29	rib	3.3	42.6	15.2	-20.3	12.1
126	female	25-45	rib	3.2	42.7	15.6	-19.6	12.9
204	female	20-30	rib	3.2	42.4	15.2	-19.8	11.3
269	male	30-40	rib	3.3	42.6	15.3	-19.2	12.0
275	female	25-40	rib	3.3	42.9	15.3	-20.8	11.1
277	male	35-45	rib	3.3	43.1	15.2	-19.6	11.6
368	female	25-45	rib	3.4	42.0	14.5	-20.0	11.9
371	female	30-40	rib	3.7	45.1	14.2	-21.2	12.3
374	male	35-45	rib	3.2	42.0	15.3	-19.6	11.5
380	male	20-30	rib	3.2	42.8	15.6	-19.9	11.5
382	male	25-35	rib	3.2	41.9	15.1	-19.5	12.3
400	female	35-45	rib	3.3	42.8	15.1	-19.8	12.1
405	female	25-45	rib	3.4	44.0	15.3	-20.7	9.9
413	male	25-35	rib	3.3	42.0	14.9	-19.4	12.5
469	female	30-40	rib	3.4	43.5	14.8	-20.4	11.7
510	male	25-35	rib	3.2	42.6	15.5	-19.8	11.3
517	female	25-35	rib	3.3	42.9	15.3	-20.4	11.0
593	male	30-40	rib	3.4	43.8	15.1	-20.0	11.8

Table 2 Stable isotope values and summarised information of various populations from northern Europe.

Site	Location	Period	N	$\delta^{13}C$ Mean	$\delta^{13}C$ Min.	$\delta^{13}C$ Max.	$\delta^{15}N$ Mean	$\delta^{15}N$ Min.	$\delta^{15}N$ Max.	Interpretation of isotope values	Source
Stavanger, Norway	coastal	Viking Age	2	-20.7	–	–	10.8	–	–	terrestrial-based diet	van der Sluis et al (2016) Journal of Archaeological Science: Reports
Sigtuna, Sweden	coastal	Medieval	5	-20.2	-21.0	-19.3	13.3	12.7	14.3	terrestrial-based diet, contribution of freshwater protein	Linderholm and Kjellström (2011) Journal of Archaeological Science
Næstved *leprosarium*, Denmark	**coastal**	**Medieval**	**19**	**-20.0**	**-20.8**	**-19.2**	**11.7**	**9.9**	**12.9**	**terrestrial-based diet, some contribution of freshwater resources, limited contribution of marine resources**	**present paper**
Dalheim, Germany	inland	Medieval	24	-20.0	–	–	9.9	–	–	terrestrial-based diet, "[...] without evidence of marine resource input into the diet" p.1053	Olsen (2018) Archaeological and Anthropological Sciences
Bishopstone, England	coastal	Late Anglo-Saxon	8	-19.9	–	–	–	9.7	10.9	"[...] diet predominantly based upon temperate terrestrial C3 with a possible small marine component", p. 202	Marsall et al. 2010, in: The Later Anglo-Saxon Settlement at Bishopstone: a downland manor in the making. Council for British Archaeology Research Report 163
Stavanger, Norway	coastal	Post-reformation	7	-19.4	–	–	12.9	–	–	"[...] decreased amount of marine protein consumption [...]", p. 130	van der Sluis et al (2016) Journal of Archaeological Science: Reports

Northern England	coastal and inland	Medieval	77	-19.4	-20.6	-18.1	12.2	10.5	14.9	mixed terrestrial, freshwater and marine diet	Müldner and Richard (2005) Journal of Archaeological Science
Stavanger, Norway	coastal	Early Medieval	9	-18.7	–	–	13.7	–	–	"The highest stable isotopic values, suggesting considerable marine consumption,were observed in the early Medieval individuals, [...]", p. 132	van der Sluis et al (2016) Journal of Archaeological Science: Reports
Gotland, Sweden	coastal	Early Medieval	6	-17.2	–	–	11.6	–	–	mixed terrestrial and marine diet	Kosiba et al. (2007) Journal of Anthropological Archaeology
Træna, Norway	coastal	Early Medieval	11	-16.9	-19.0	-15.7	–	–	–	mixed terrestrial and marine diet	Johansen et al (1986) Radiocarbon
Flakstad, Norway	coastal	Stone Age	2	-13.4	-14.0	-12.8	–	–	–	"[...] a diet of more than 90% marine food, especially fish, seems likely", page 757	Johansen et al (1986) Radiocarbon

Table 3 Descriptive statistics of the isotope values of skeletons with leprosy bone lesions from the leprosy hospitals at Næstved and Winchester (Roffey et al. 2017) and from medieval Norwich (Bayliss et al. 2004) and Sigtuna (Linderholm and Kjellström, 2011).

Site	N	$\delta^{13}C$ Mean	$\delta^{13}C$ Min.	$\delta^{13}C$ Max.	$\delta^{15}N$ Mean	$\delta^{15}N$ Min.	$\delta^{15}N$ Max.
Næstved *leprosarium*	19	-20.0	-20.8	-19.2	11.7	9.9	12.9
Winchester *leprosarium*	43	-19.3	-20.5	-18.2	10.5	8.7	13.1
Norwich	8	-19.1	-19.9	-17.9	11.3	10.0	13.5
Sigtuna	5	-20.2	-21.0	-19.3	13.3	12.7	14.3

Table 4 Descriptive statistics of the isotope values of human data from the leprosy hospital at Næstved and the Danish medieval sites: Holbæk (Jørkov et al. 2009), Øm Kloster, Viborg and Ribe (Yoder, 2010).

Site	N	$\delta^{13}C$ Mean	$\delta^{13}C$ Std	$\delta^{13}C$ Min.	$\delta^{13}C$ Max.	$\delta^{15}N$ Mean	$\delta^{15}N$ Std	$\delta^{15}N$ Min.	$\delta^{15}N$ Max.
Næstved *leprosarium*	19	-20.0	0.4	-20.8	-19.2	11.7	0.7	9.9	12.9
Holbæk	58	-19.4	0.6	-20.3	-18.0	11.8	0.8	9.9	13.8
Øm Kloster	98	-19.7	0.5	-20.6	-18.5	12.0	0.9	9.8	14.6
Viborg	45	-19.2	0.4	-20.1	-17.9	12.4	0.7	10.8	13.5
Ribe	54	-19.2	0.5	-20.5	-17.9	12.8	0.9	10.9	14.3

Table 5 Mean values of the leprosy patients from Næstved and of the three social groups from Øm Kloster (Yoder, 2010).

Site	Social group	$\delta^{13}C$ Mean	$\delta^{15}N$ Mean
Øm Kloster	Elites	-19.9	12.5
Øm Kloster	Monks	-19.8	12.3
Øm Kloster	Peasants	-19.9	11.6
Næstved	Leprosy patients	-20.0	11.7